

Problems with Repressurization

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ABSTRACT

This technical note describes some of the problems associated with the cerebrospinal and vascular repressurization of human surrogates used in UMTRI biomechanics impact experiments. The repressurized postmortem subjects were unembalmed cadavers and Rhesus monkeys.

Cerebrospinal Repressurization

The cerebrospinal repressurization techniques developed for postmortem Rhesus monkeys were similar to those used for repressurizing unembalmed cadavers [1,3-5]. Each Rhesus monkey required surgery in two areas: the lumbar spine and the skull. A small hole was cored in the L6 lumbar vertebra and a Foley catheter was inserted under the dura of the spinal cord such that the balloon of the catheter reached mid-thorax level (See Figure 1). The point at which the catheter passed through the lamina of the sixth lumbar vertebra was sealed with plastic acrylic, and the incision over the spine was sewn closed before the head was prepared. After the scalp was removed from a small area over the right and left sides of the frontal bone, the bony surface was sanded. Next, two 3 mm diameter holes for the pressure transducer couplings were drilled using a Stryker bone coring tool, and the bone was tapped. Aluminum couplings for the pressure transducers were screwed into the tapped holes. Dental acrylic was applied around the base of the couplings to secure them. To check fluid flow through the ventricles, saline was injected through the Foley catheter until it rose to the top of the couplings in the skull. The couplings were capped until the pressure transducers were attached in the impact laboratory.

For cadavers, a small hole was cut into the L2 lumbar vertebra and a Foley catheter was inserted under the dura of the spinal cord such that the balloon of the catheter reached mid-thorax level. The point at which the catheter passed through the lamina of the lumbar vertebra was sealed with plastic acrylic and sewn closed (See Figure 2). A 1.0 cm diameter circle of scalp was removed over each of the following areas: the frontal, left parietal, right parietal, and occipital bones. A Stryker bone coring tool was used to make holes in the skull for pressure transducer couplings using a circular bit. The four holes were located out of the planned contact area for the impacting surface and were not drilled into the skull sutures. The dura mater under these holes was perforated without cutting the brain tissue. Next the holes were tapped and brass transducer couplings were screwed into the holes. Two pinhead screws were attached 2.0 cm from each coupling. Quick-setting acrylic plastic was molded around the screws and the base of each coupling as a mooring device. To check fluid flow through the ventricles, saline was injected through the Foley catheter until it rose to the top of the couplings. The couplings were capped until the pressure transducers were inserted in the impact laboratory.

Occluded balloon
maintains catheter
position

Catheter inserted
through lamina of
lumbar vertebra
into dura mater

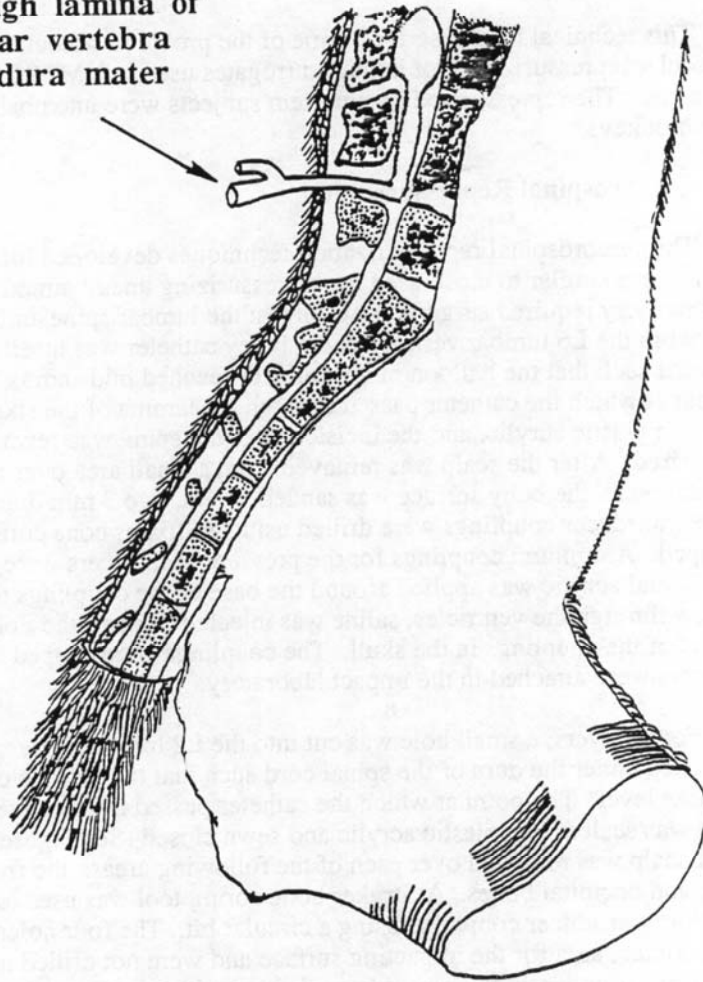


Figure 1. Cerebrospinal Repressurization of a Rhesus monkey

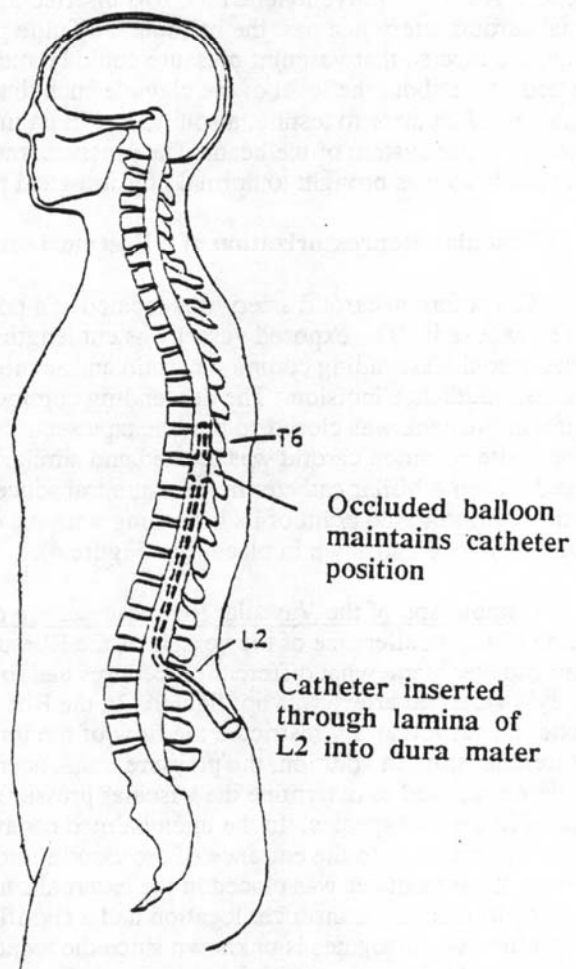


Figure 2. Cerebrospinal Repressurization

Vascular Repressurization of a Cadaver Head

The common carotid artery was located at a point in the neck and an incision was made (See Figure 3). A balloon catheter was inserted and positioned such that the balloon was in the internal carotid artery just above the point where the external carotid artery branches. A narrow polyethylene tube was inserted at the same point and ran into the internal carotid artery just past the balloon. A Kulite pressure transducer was then fed through the tube so that vascular pressure could be monitored. Finally, the vertebral arteries were tied off at about the level of the clavicle such that fluid pressure in the head was maintained. Just prior to testing, a solution of India ink and saline was released from a tank into the vascular system of the head. The pressure transducer was used to monitor the flow so that the head was brought to normal physiological pressure just prior to impact.

Vascular Repressurization of a Postmortem Rhesus monkey Head

The common carotid artery was located at a point in the neck and an incision was made to expose it. The exposed vessel was cut lengthwise. A polyethylene tube was inserted into the ascending common carotid and secured with string and tape above and below its lengthwise incision. The descending common carotid was ligated. Next the incision in the neck was closed so that the tape securing the tube was stitched to the neck. The opposite common carotid was located and similarly prepared. Vascular flow was checked. Then a Millar catheter tip pressure transducer was inserted into the ascending common carotid to the point of its branching with the external carotid. The catheter was secured with tape and sewn in place (See Figure 4).

Comparison of the Vascular Repressurization of the Head of Man and Monkey -

Because of the smaller size of the vessels of the Rhesus monkey compared to those of the human cadaver, somewhat different procedures had to be used (See Figure 5). The Rhesus monkey's vertebral artery was not ligated. In the Rhesus monkey, the pressure transducer in the external carotid artery restricted the flow of the internal carotid artery at the measurement site. In addition, the pressure transducer used to monitor the carotid pressures, and, therefore, used to determine the vascular pressure in the brain, was placed in different locations in the two species. In the unembalmed cadaver, the transducer was placed in the internal carotid close to the entrance of the carotid into the brain. In the postmortem Rhesus monkeys, the transducer was placed in the external carotid distal to the brain. Whether this difference in pressure transducer location had a significant effect on the experimental results between the two surrogates is unknown since the location of the pressure transducers may have produced initial repressurization levels that were not identical. Also, it was more difficult to remove the air in the skull-brain area of the Rhesus monkey, and, therefore, a greater proportion of the monkey's brain cavity may have contained air than the human cadaver's.

Over time, air or gas will develop in the skull. When this happens, artificial motion of the brain will occur during impact (See Figure 6). It is possible to remove most of the gas by proper repressurization techniques (See Figure 7). This requires the use of pre-test x-ray.

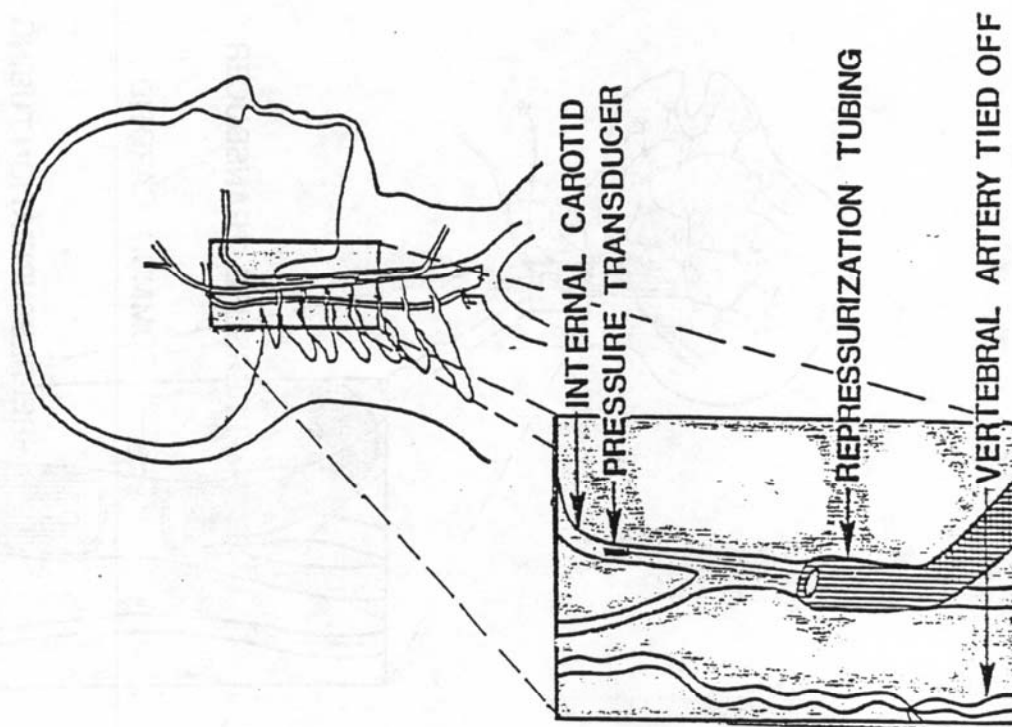


Figure 3. Vascular Repressurization

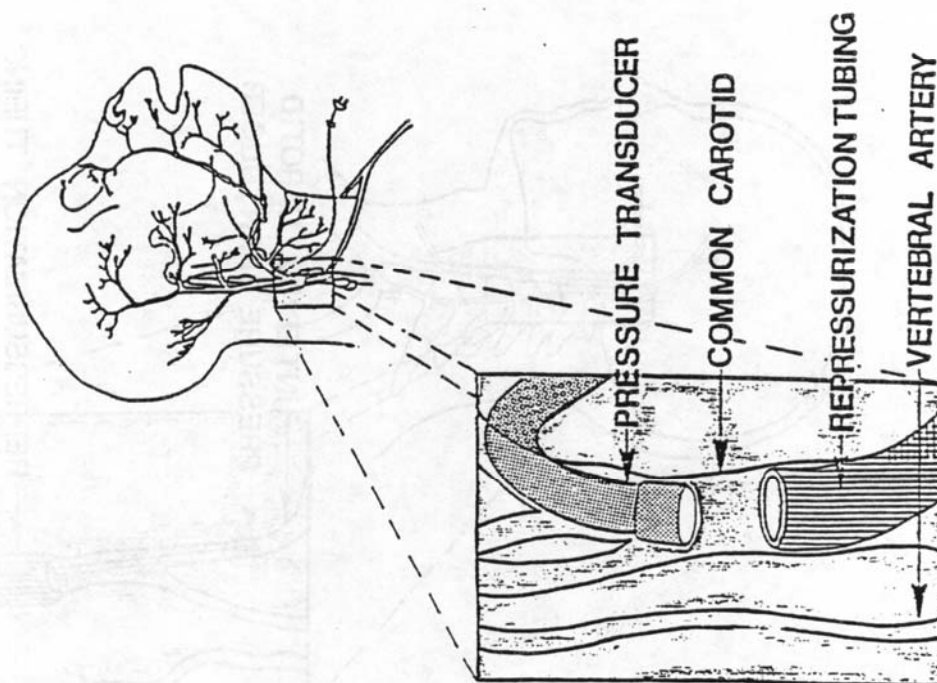


Figure 4. Vascular Repressurization of a Rhesus monkey

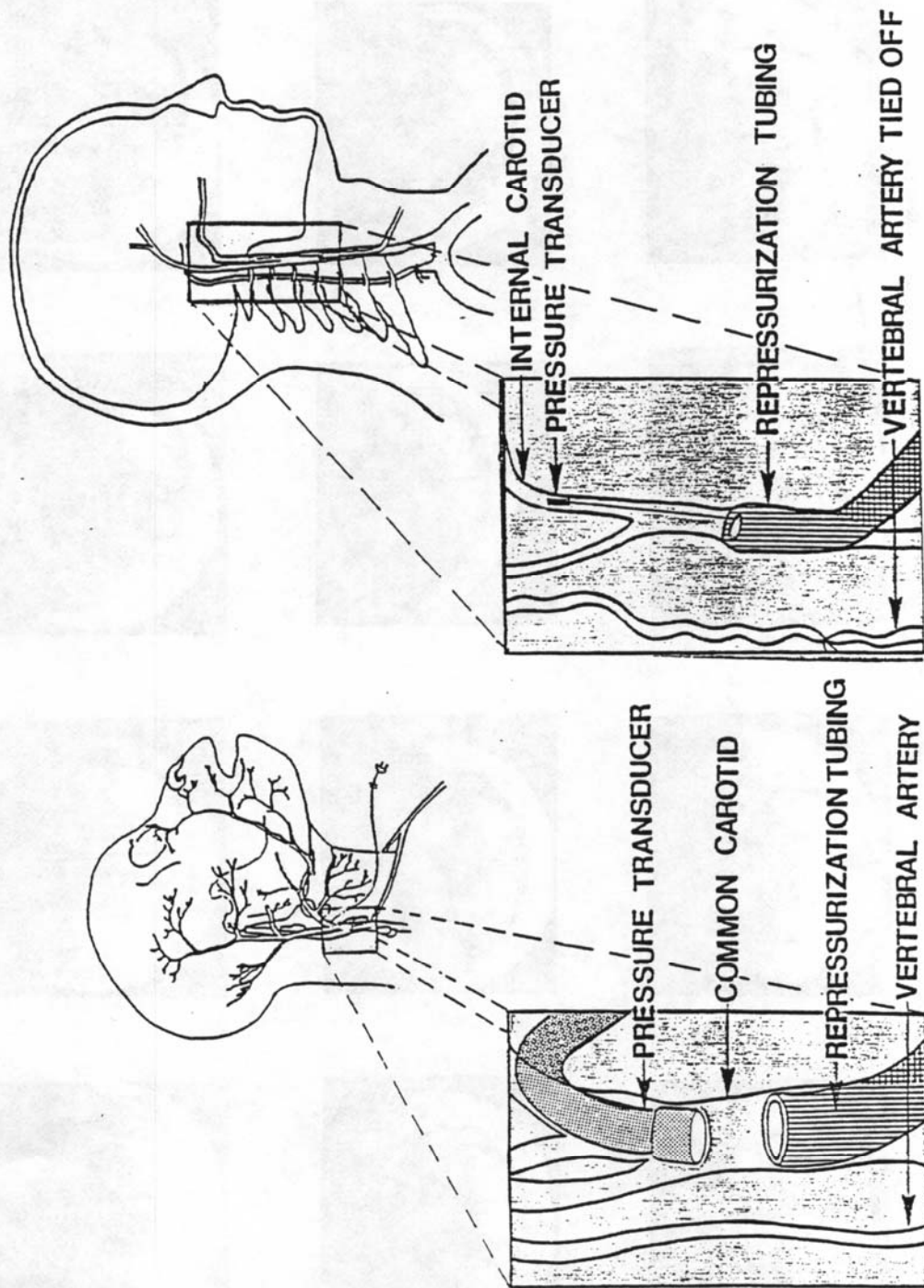


Figure 5. Comparison of Vascular Repressurization Procedure for a Rhesus monkey and a cadaver

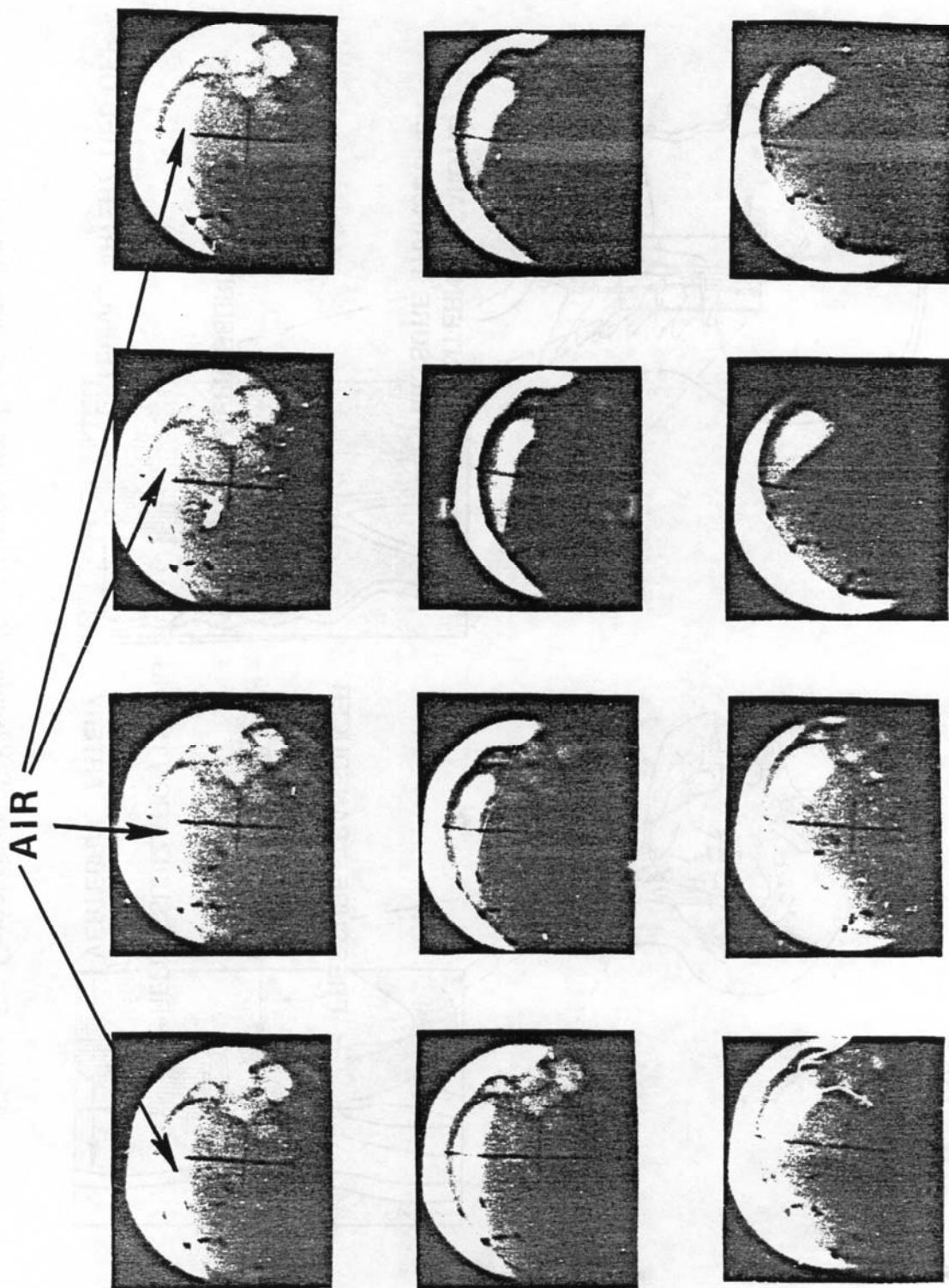


Figure 6. Presence of Air/Gas

NO AIR-FULLY REPRESSURIZED

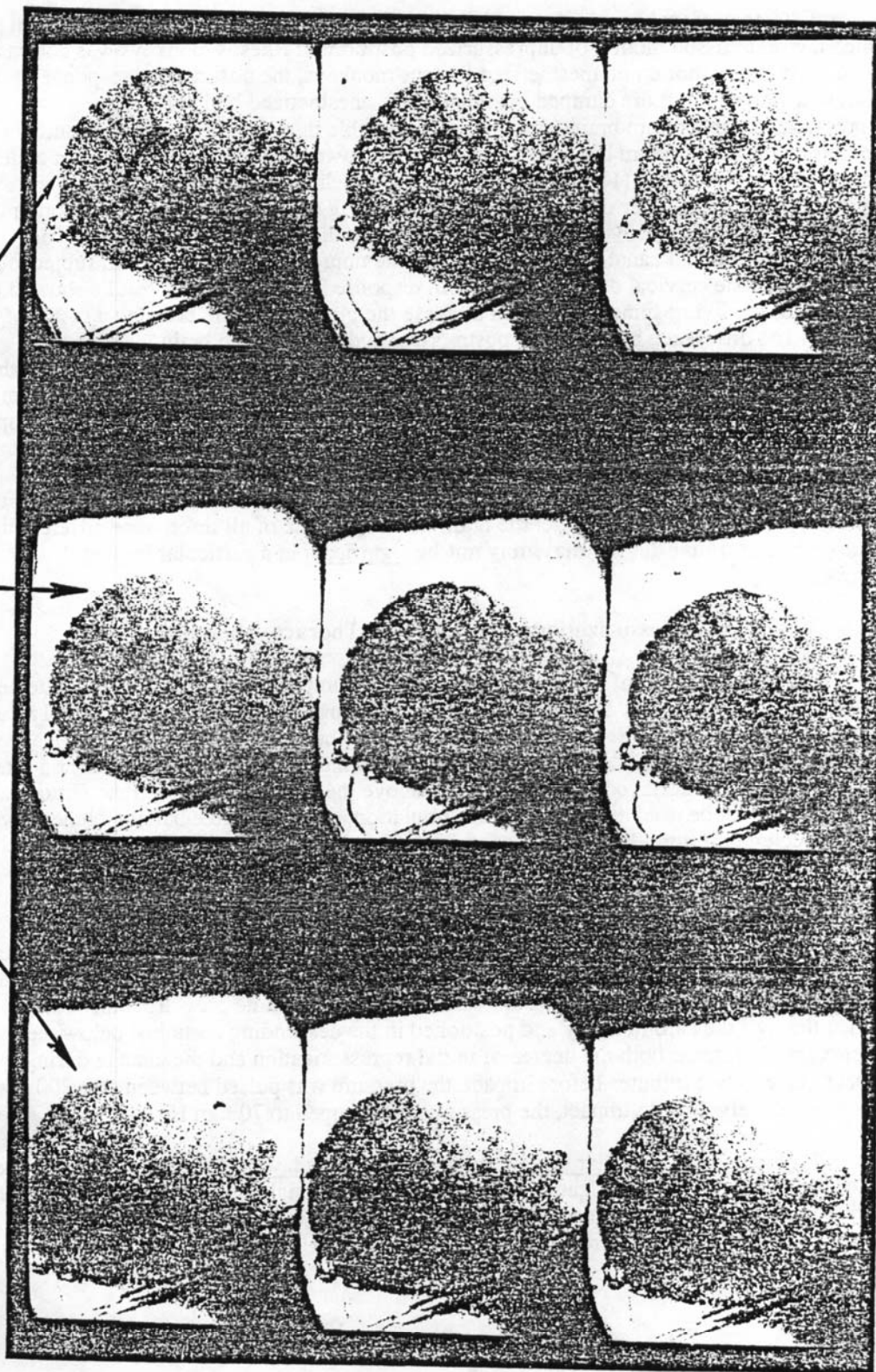


Figure 7. Absence of Air/Gas

Effects of Cerebrospinal and Vascular Head Repressurization - In a study in which the brain tissue motion of unpressurized postmortem Rhesus monkeys was contrasted to the brain tissue motion of anesthetized Rhesus monkeys, the postmortem response of the brain was slower and more damped than that of the anesthetized brain [1]. The unpressurized postmortem brain was more compressible than the anesthetized brain; pressure in the postmortem brain was lower than what would occur in the live brain under similar impact conditions [1]. This lower pressure is believed to be due not only to the degradation of tissues after death, but also to fluid being easily expelled out of the brain into the unpressurized arteries, veins, and the space surrounding the cervical cord [1]. The unpressurized cervical canal and flaccid neck of the unpressurized postmortem subject also may uncouple the cervical cord from the brain response [1]. The study's results showed that the effect of the living spinal cord could increase the pressures in the brain by a factor of four [1]. The difference between the postmortem and anesthetized brain response was greatest when the head was subjected to superior-inferior impact accelerations because the effect of a "fully pressurized" cervical cord was lacking in the unpressurized postmortem subject [1]. These results implied that one impact effect of the living non-anesthetized spinal cord probably is to increase intracranial pressure [1]. An experiment reported at the 30th Stapp Car Crash Conference showed that the brain tissue response of repressurized postmortem Rhesus monkeys was more similar to that of anesthetized ones than was that of unpressurized Rhesus monkeys, yet the brain tissue response of all three were different to some degree and that degree may/may not be significant in a particular impact environment [5].

Vascular Repressurization of the Cadaver Thoraco-Abdomen

Surgical insertion of Foley catheters followed three patterns depending on whether access through the femoral arteries was possible. Through an incision in the femoral artery, a catheter was guided up the arterial system, where the balloon occluded the aortic termination. Another catheter was guided through an incision in the common carotid artery into the descending aorta, occluding it slightly above the diaphragm. When the femoral arteries could not be used due to plaque accumulation, either a double balloon catheter was used to occlude the aorta below the diaphragm and at the common iliac arteries, or two catheters, one in each common carotid artery, were used to occlude the aorta below the diaphragm and at the common iliac arteries. The repressurizing fluid was introduced via the catheters through a channel in the center of the two occluding balloons. For thoraco-abdominal impact testing, it is critical that the liver be fluid-filled before impact. This was accomplished by repressurizing the area between the two occluding balloons above normal physiological pressure with an India ink-saline mixture. A Kulite pressure transducer, guided through the carotid artery and positioned in the descending aorta just below the diaphragm, monitored both the degree of initial repressurization and the change during impact. One to two minutes before impact, the pressure was pulsed between 100-200 mm Hg. Immediately prior to impact, the pressure was dropped to 70 mm Hg.

Problems with Vascular Repressurization of the Cadaver Thoraco-Abdomen - The major problem with repressurization of the thoraco-abdominal region is getting reasonable repressurization in all of the necessary organs. In general, if one region is properly repressurized, other regions are either over- or under-repressurized. Therefore, if a target

organ such as the liver is chosen to be properly repressurized, this implies that the other regions probably are not repressurized to the degree preferred. Although it was clear from inspection of the abdominal organs at autopsy that, in most cases, those organs had been profused with the India ink-saline mixture, it was not clear how much of the turgor lost due to the postmortem state of the subject had been returned by the repressurization process [2]. All incisions must be sealed to contain the fluids.

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DISCUSSION

PAPER: Problems with Repressurization

SPEAKER: G. Nusholtz

Q: C. Tarriere, Peugeot-Renault

Do you have a specific dye marker that you use?

A: Basically it's a gel that's formed out of regular gelatin, cornstarch, sodium iodine, and a little bit of baking soda and stir it at a certain temperature and put it in the oven for two hours, what we do is get a neutral density, you add just a touch of baking soda which reduces it to a very fine area and radio paint dye is sodium iodine.

Q: Do you use india ink?

A: Are you talking about the x-ray dye?

Q: Something about x-ray movie. Do you use a particular, specific particle?

A: Sodium iodide.

Q: Steve Ohana, General Motors

For the vascular repressurization do you get rid of the coagulated blood first by some method, whatever is in the vascular system?

A: I wouldn't know how you'd do that without opening him up and cleaning out the arteries. The one thing that we, I can do is try to blow them out by pressurizing the bit above and the criteria I use is to inflate it enough so that I get the skull, the brain up against the skull.

Q: For the other organs though doesn't the pressurization force some clotted blood into the smaller capillary areas?

A: It has to, that's the problem, you don't always get the fluid everywhere you want. Particularly with the liver. The kidneys are real easy to pressurize you can get the fluid wherever you want and things like the pancreas are the same, but when you go to the liver, you've got to try something a little more drastic than just dumping fluid into the arterial system.

Q: You need a vascular roto-rooter?

A: Yeah, something like that.

Q: Mike Walsh

How long, I think we talked about this a couple of years ago, but how long do you feel, or in your experience it takes for a

significant amount of air to get into the cranial cavity? How long after death?

A: That actually depends on the temperature that they're kept at. We had a subject that came in and I think it was about 48 hours but the coolers at the morgue had died so they just left them out on the slab, and when they called they didn't tell us this, they just said oh we've got one here and he's about two days dead, or 24 hours, and we came and brought him over and I looked at him there was an awful lot of air in there. And it's also possible, the other thing is we have to drill through the skull to put pressure transducers in and when you do that you're automatically going to introduce air.

Q: Alright but at that point you repressurize and push whatever air is in there either induced by you, or osmosis if you will, out?

A: Right.

Q: Another question I think you just answered it. You can see just on your normal still x-ray, you can see when you have air in that cranial cavity is that right?

A: That's correct. Yes. In one case we took an x-ray before and the head was tilted just enough so we didn't see the air that was in there and we thought we had it removed but then after we hit it and we saw in the motion that there was a little bit of air there. But normally you can see on a normal still x-ray whether there's air in there or not.

Q: Okay. What criteria do you use to determine whether, which vessel you go into for pressurization of the thorax and the abdomen? You can go in, as you say, through the subclavians, the carotids, the femorals, what makes that decision for you?

A: In part it's decided by what I'm after, if I'm primarily after the thorax then I probably take a fifty fifty percent choice on whether I want to go into the carotids or come in through the femorals. When I'm doing the abdomen I would like to come into the femorals if I can get tubes and catheters up there. I can't always do that in which case then I have to come down to the carotid. So the criteria that dictates my choice is the ease of getting the tubes all the tubes that I have to get in there, in there and be able to check on x-ray to see if they're there.

Q: Last question. What kind of landmarks do you use, how do you determine with certainty or with reasonable certainty where you are when you, as you say drop these balloons? What kind of anatomical landmarks do you use to determine where those two balloons are?

A: Primarily I just use the diaphragm because you can see a distinct line between where the liver is and where the lungs

are because the fact the lungs are filled with air so it shows up very dark. So if I can get one balloon right above the diaphragm, this is just for the liver lets say, I try to get the other one about 4 inches down below that.

Q: Okay. For example you say you could always do a spline. But what do you use if you're doing a spline, you use the same type of criteria?

A: That would be the same criteria. What I want to do is, there's a real problem with pumping too much fluid into the thorax and when you go to a high pressure to get a target organ. What you can do is if you pressurize the whole thorax at 200 millimeters your just going to inflate. I've had problems where we've gone up to 200 millimeters to try and get a target organ and an arm starts to really billow out. That's the only reason that you have to use ballons is when you are after a target area.

Q: Thank you.

Q: Unnamed, GM Research
I wonder when you repressurize the arterial system do you get fluid in the venous system as well? The dye that you use, such as indian ink, do you see that in your venous system?.

A: We have in several instances because what's happened in a couple of the liveran packs we've torn the hepatic-portal vein and when we open them up the abdomen is just filled with dye so we obviously had gotten it into that area. So we did get it through the arterial system and into the venous system.

Q: Do you feel the observation of leakage of the ink is a good indication of contusion if it were a life subject?

A: I wouldn't really be able to answer that now. The only thing I know is when we do pressurize we generally have to hit the subject very hard to get the type of injuries that we're after. The only case where I do have some information has to do with brains in which we've done a comparative study between a live subject and a post-mortem subject and for a very limited class of injuries they did seem to be very similar but that's a very limited class of brain injuries and it's only one area of the body.

Q: So your main purpose of repressurizing your subject is to make it more life like or to contusion or what?

A: The purposes are several. One is to try and restore the pressure so that you might get some idea of what type of pressure is occurring in the arterial system. Second, is to dye injuries, like we would not have ever discovered that we

were damaging the aorta unless we had that dye in there and at lot areas you just don't, particularly for the brain you won't see anything when you hit it except you might see a skull fracture.

Q: Joseph Award, University of California

Guy we've done some tests and I noticed that when you were monitoring the pressure thoracically, you had your subject stationary and then the impacting device was brought in. But is there anyway you've successfully been able to monitor the pressure dynamically as the subject is being projected down the track and maintained any physiological pressure during the testing?

A: I've done that several times, but are you asking for the procedure and the technique of doing it or what?

Q: Well yes. I've found that in order to pressurize and maintain the pressure that you'd want to have you're also having to put in a significant amount of fluid that's going to drastically affect the weight of the thoracic region.

A: Now that's true. It's absolutely true, and once again the question is how long from once you get your pressure to the impact. What we've normally done with the sled is we have an air reservoir and we pressurize that air reservoir and this is right before we fire until we get the pressure that we want that were looking for say 70 or 80 millimeters and then we fire and there's only about 60 seconds from that point to when the impact occurs. So we try not to dump, that's a serious problem as you obviously know, is you can easily over pressure you can pressurize them and then go off and do something else maybe set cameras or adjust the gain in your accelerometers and come back and he's just billowed out.